Airborne lidar observations of mid-latitude upper-tropospheric water vapour variability

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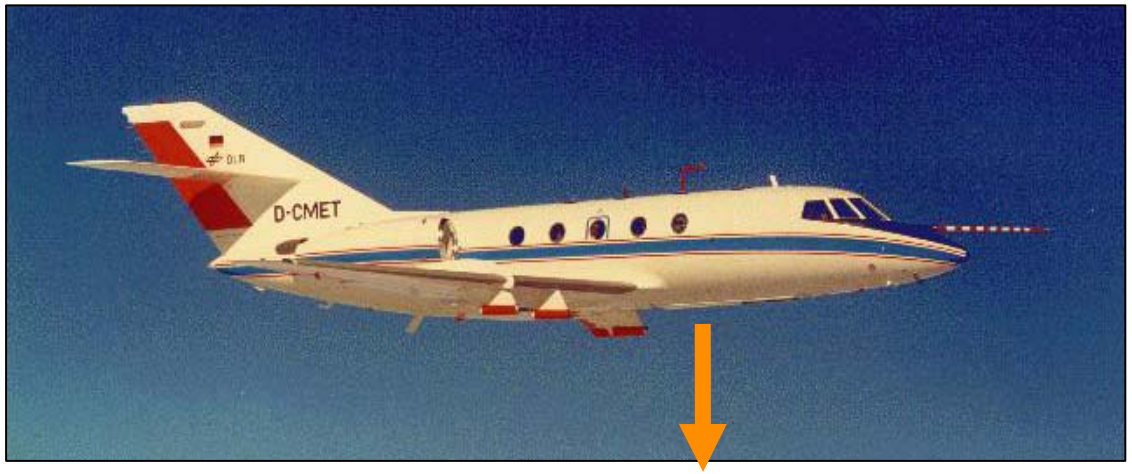
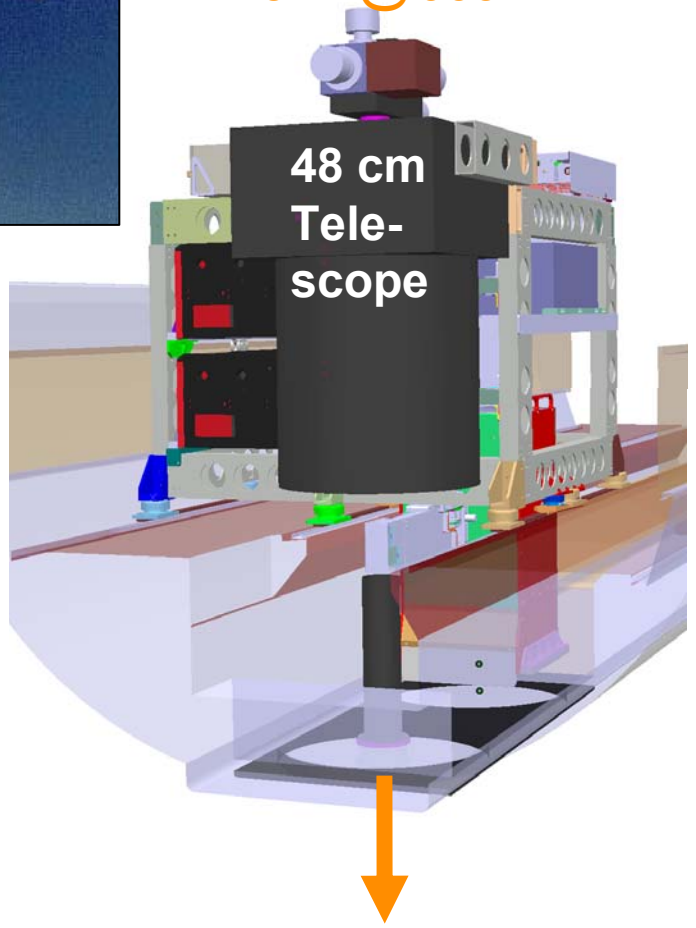
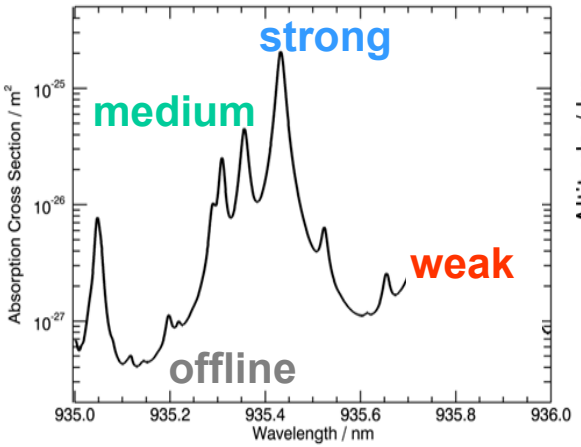
Water Vapour Differential Absorption Lidar on Falcon

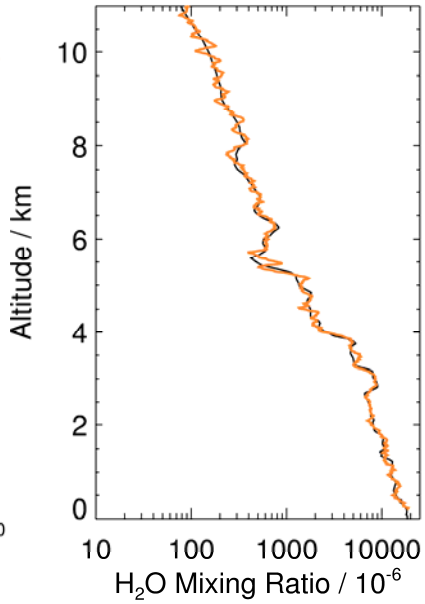


New System since 2007:
4 wavelengths, 8 W @ 935 nm

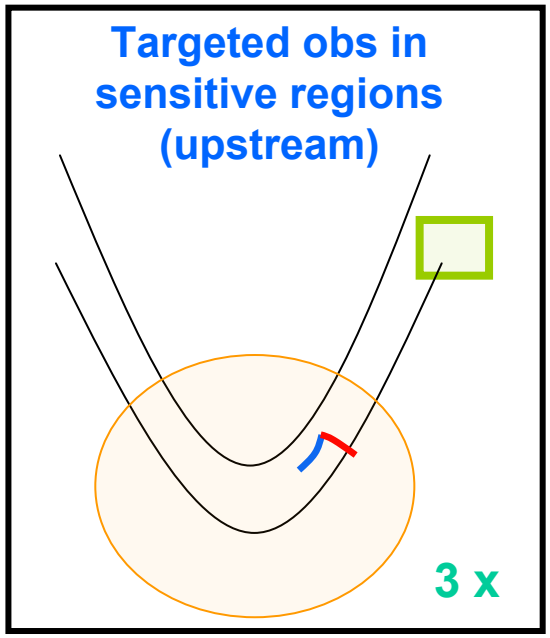


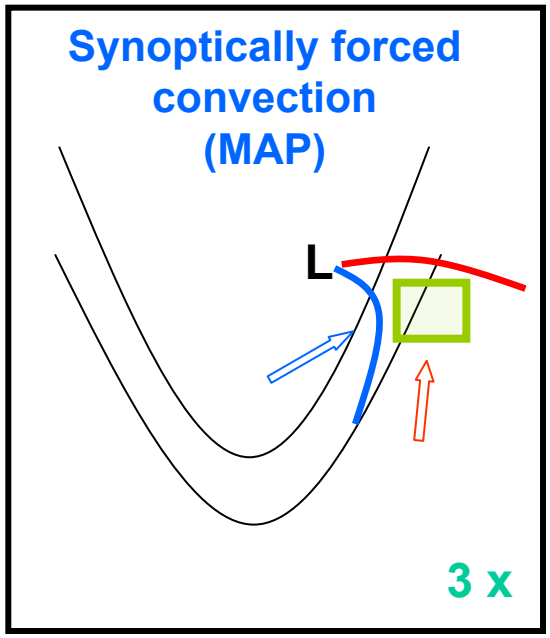
Full tropospheric profile by combining 3 abs. lines

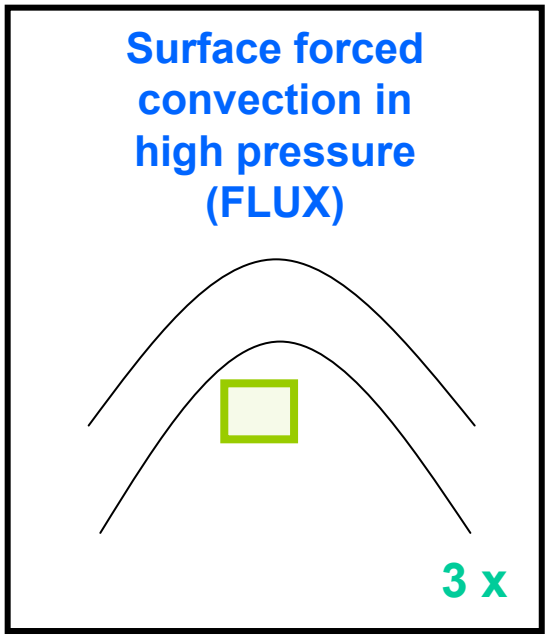


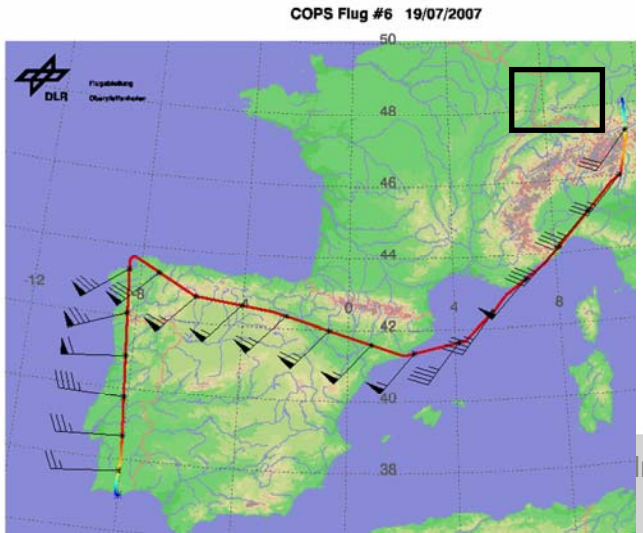


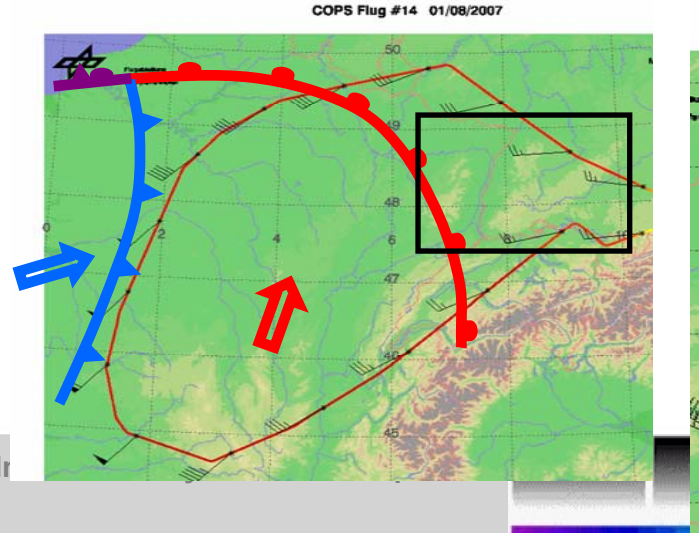
Convective and Orographically-induced Precipitation Study, COPS 2007: Lidar Objectives

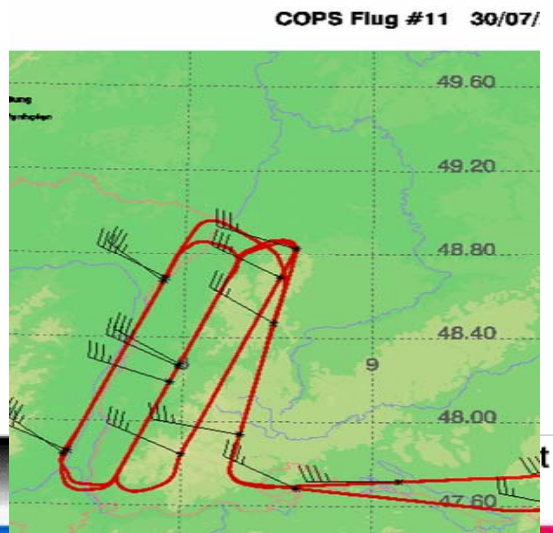




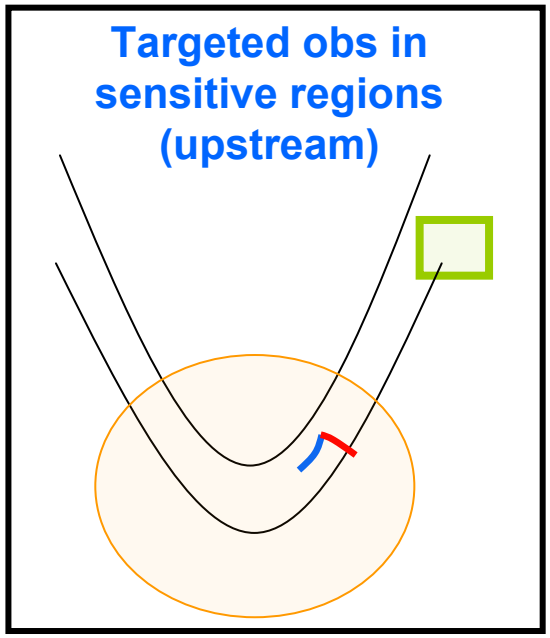


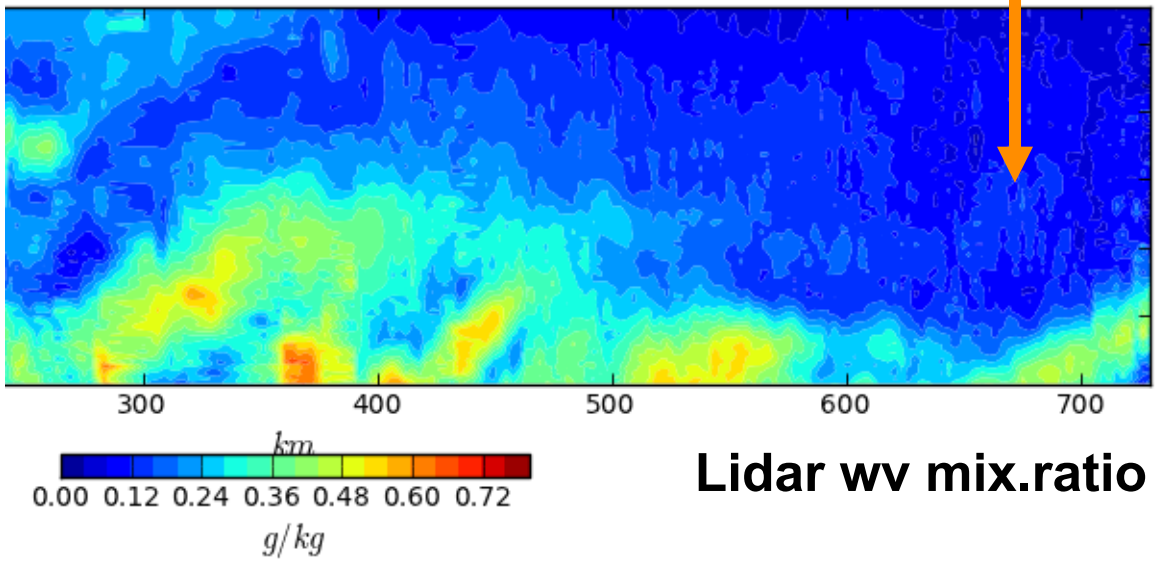




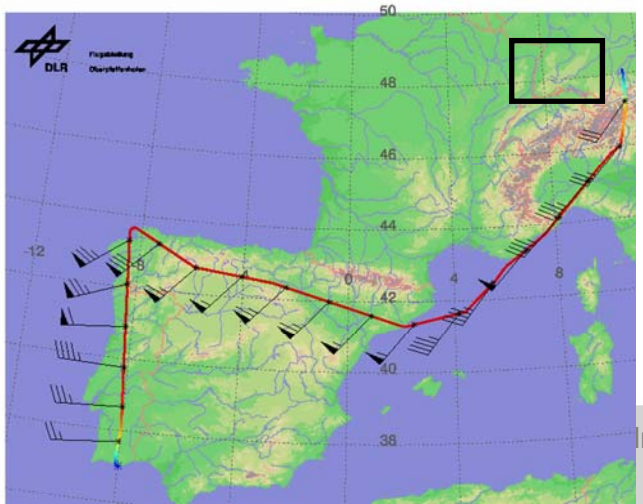


European THORPEX Regional Campaign ETReC 2007





Lidar wv mix.ratio

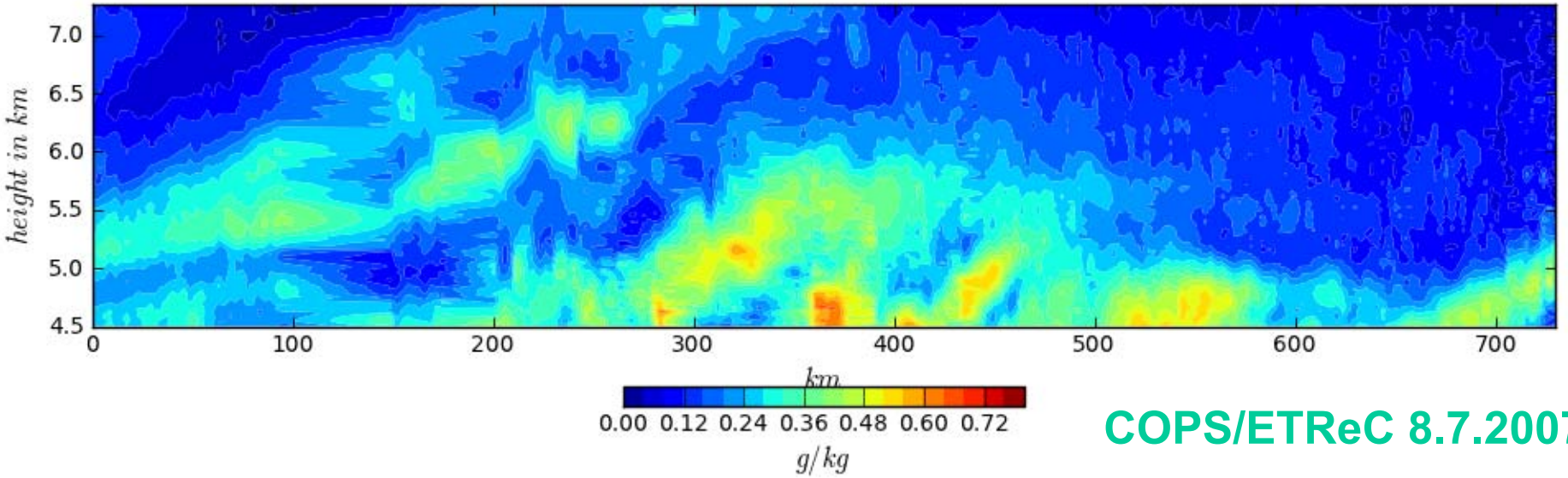


Improved initializations for precipitation forecasts, coordinated with COPS.

Upstream water vapour and wind lidar measurements, plus dropsondes,

to obtain additional data in advance of high impact weather events.

Humidity Variability in the Mid-lat. Free Troposphere

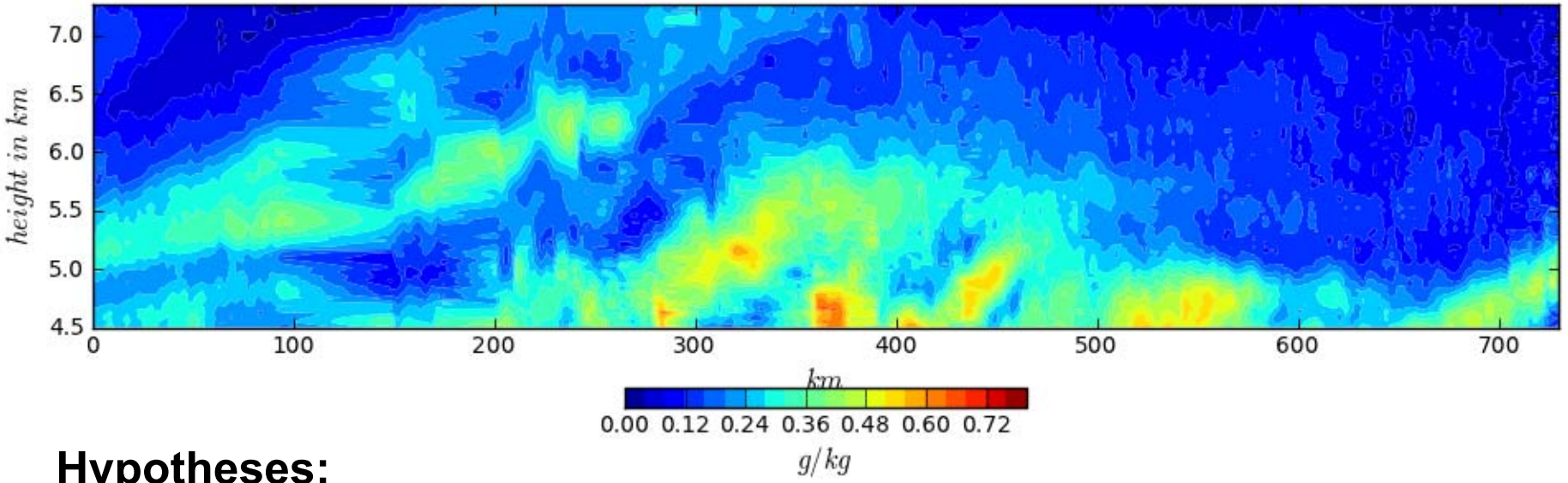


COPS/ETReC 8.7.2007

Observations:

- **Lidar wv mixing ratio, hor. res. 3 km, vert. res. ~ 300 m.**
- **Atm. dynamics dominated by large-scale processes.**
- **Humidity highly variable - implications for cloud variability.**
- **Distribution is non-stationary, non-Gaussian, intermittent.**

Humidity Variability in the Mid-lat. Free Troposphere

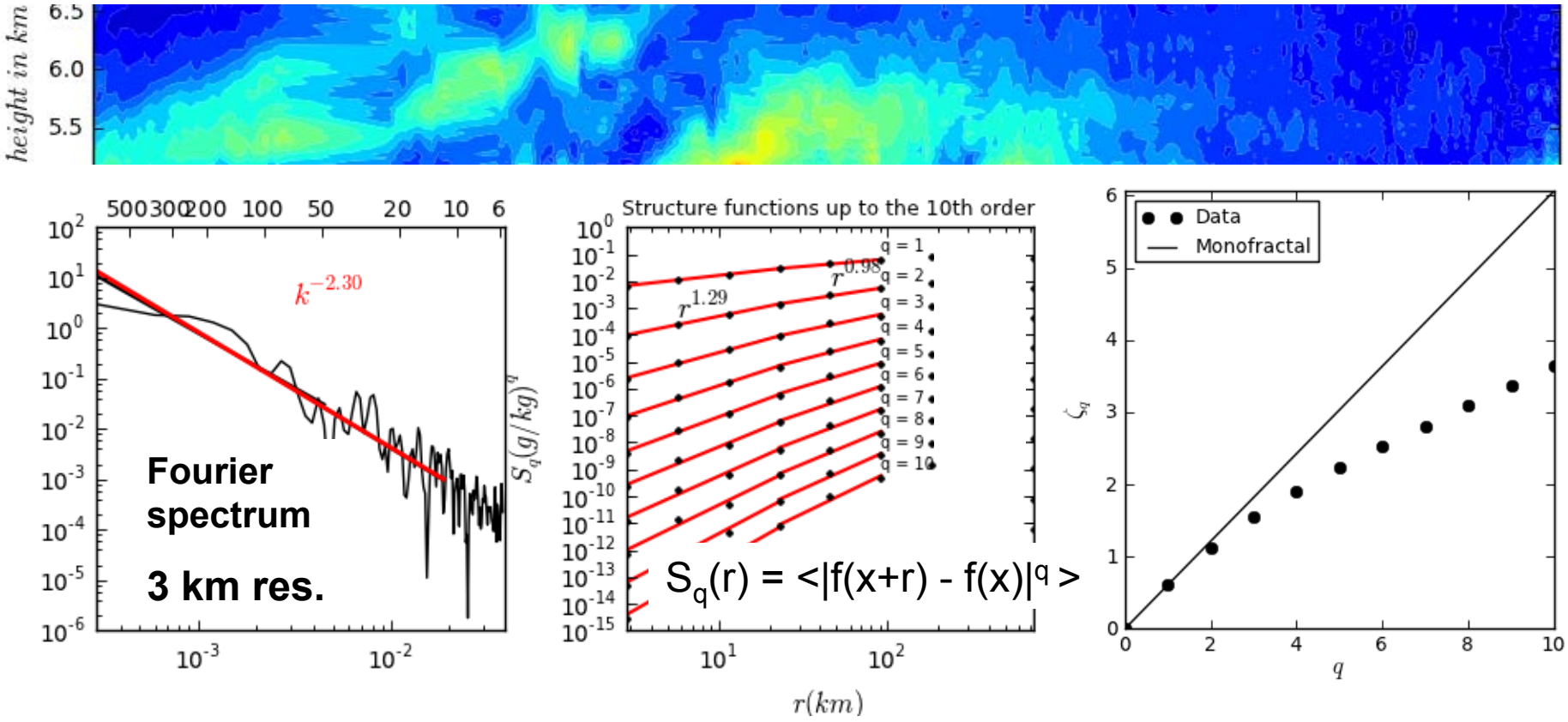


Hypotheses:

- **Summertime: humidity distribution results from transport and mixing of air initially lifted by scattered (deep) convection.**
- **Intermittency should decrease with height, smoothness increase.**
- **Fourier spectra are not adequate to characterize intermittency.**
- **Structure functions of higher order are needed** (Davis et al, 1994).

Humidity Variability in the Mid-lat. Free Troposphere

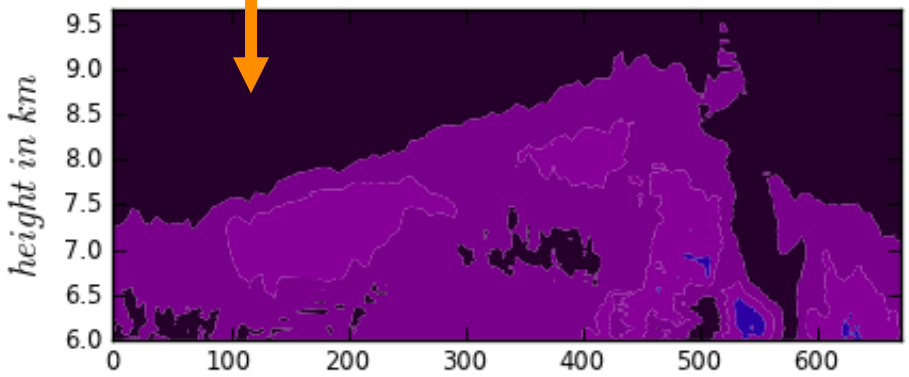
Power-law scaling $S_q(r) \sim r^{\xi q}$ observed for r ≈ 10...100 km



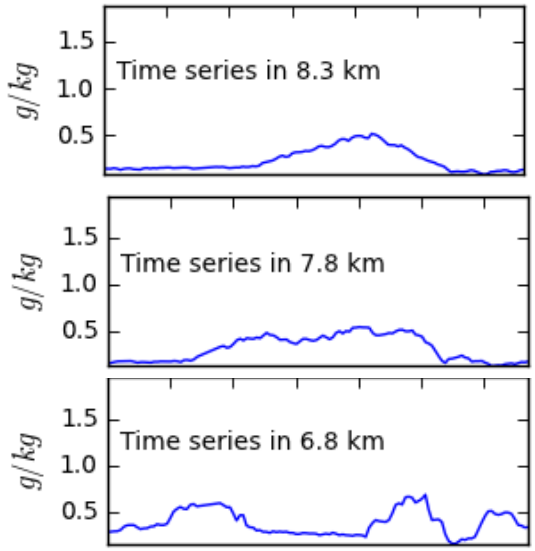
Intermittency and smoothness can be quantified by their deviation from the monofractal scaling behaviour (Pierrehumbert, 1996).

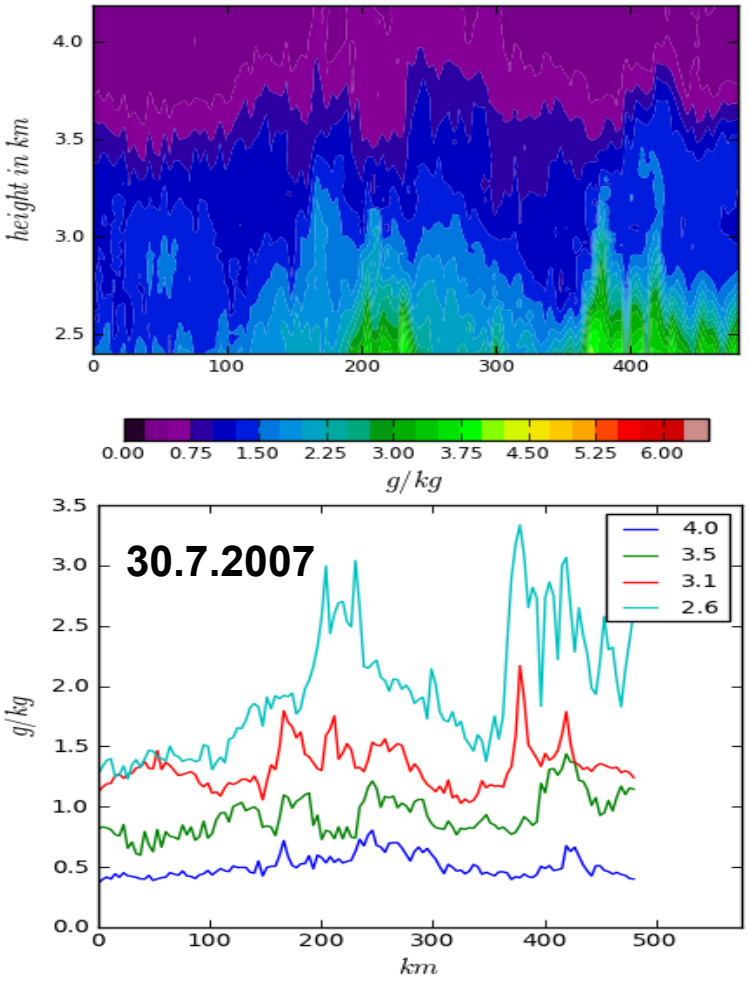
WV variability: 2 different exemplary cases

Large-scale upper-trop. advective mixing ⟺ Convection



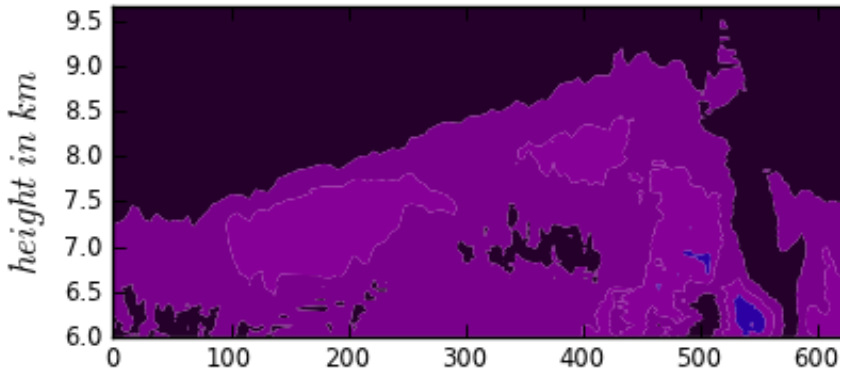
8.7.2007





8.7.07: Moderate Intermittency in Mid-Troposphere

Large-scale upper-trop. advective mixing



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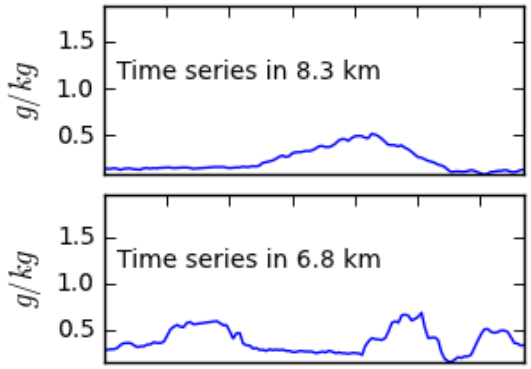
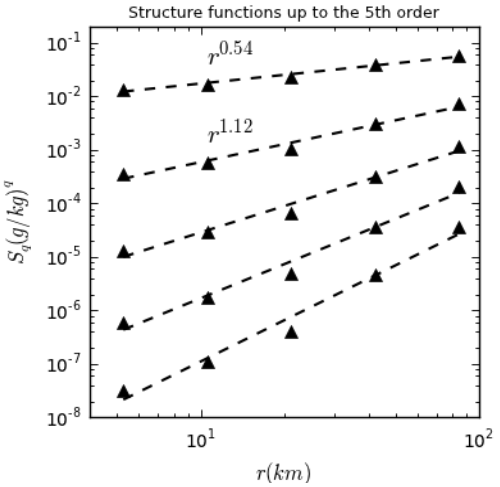
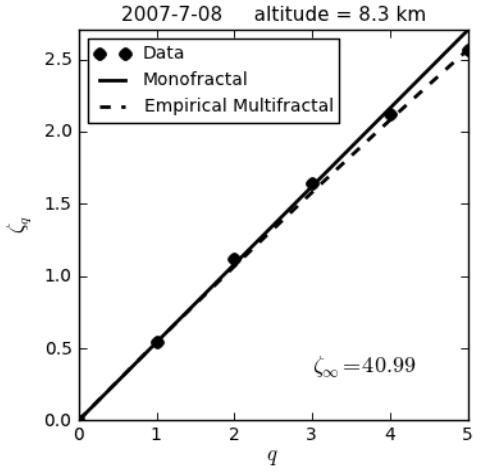
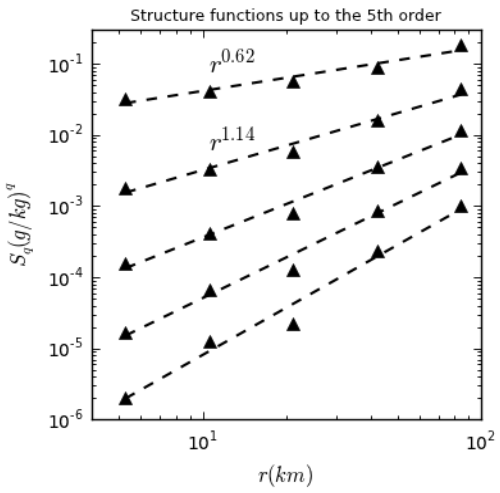
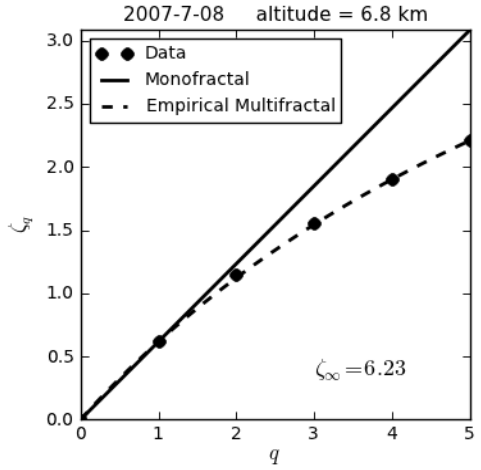






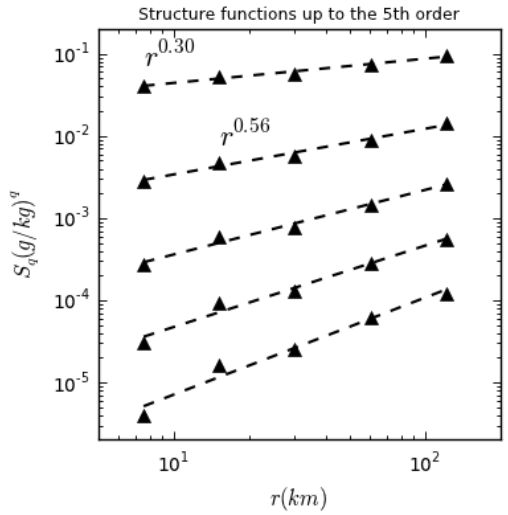


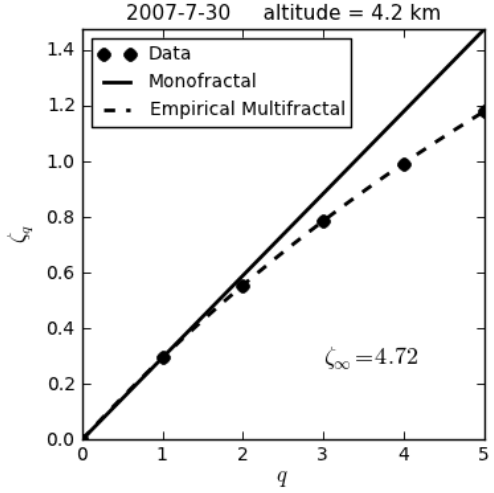


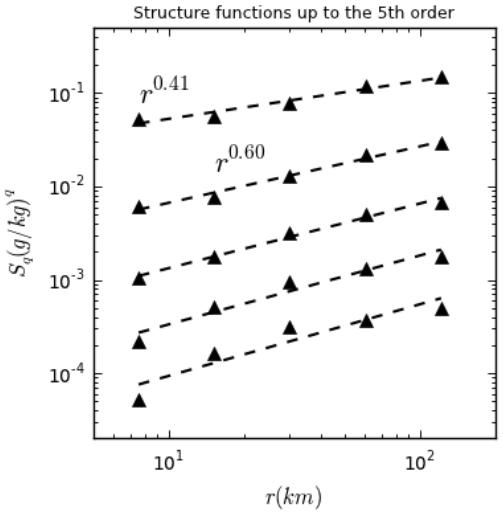
smoothness ~ ξ_1

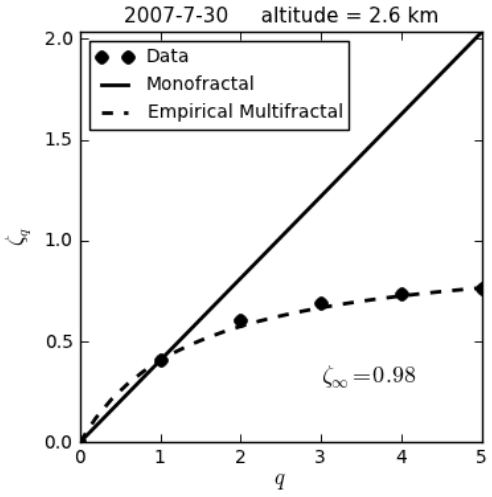
intermittency ~ $1/\xi_\infty$

30.7.07: Strong Intermittency in Lower-Troposphere





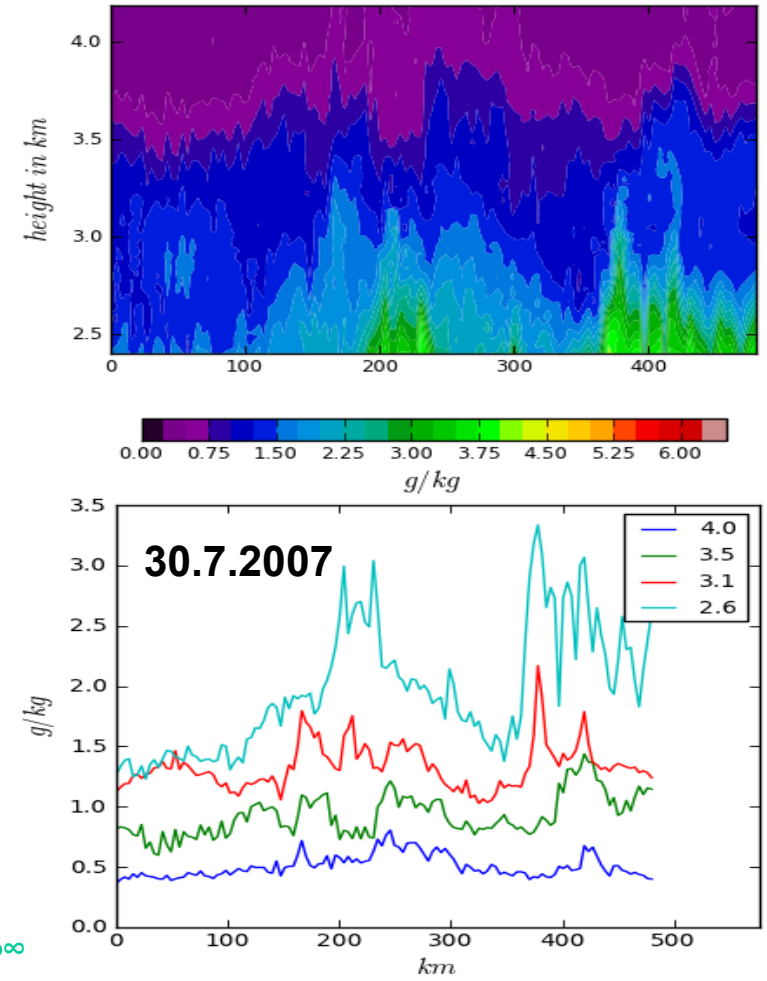




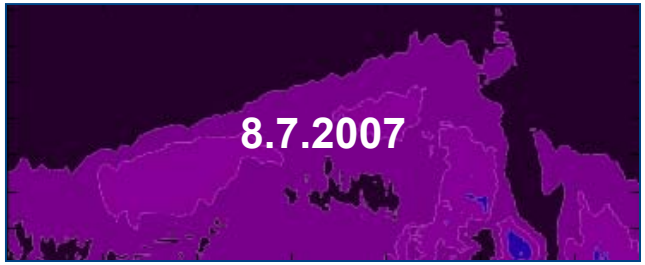
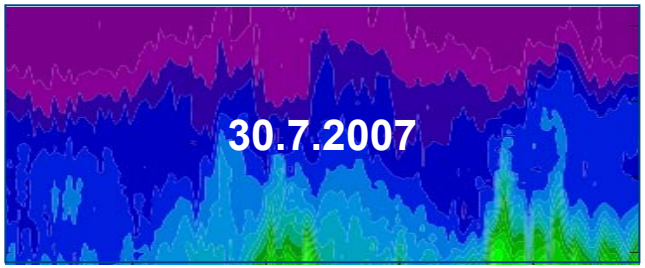
smoothness ~ ξ_1

intermittency ~ $1/\xi_\infty$

Convection



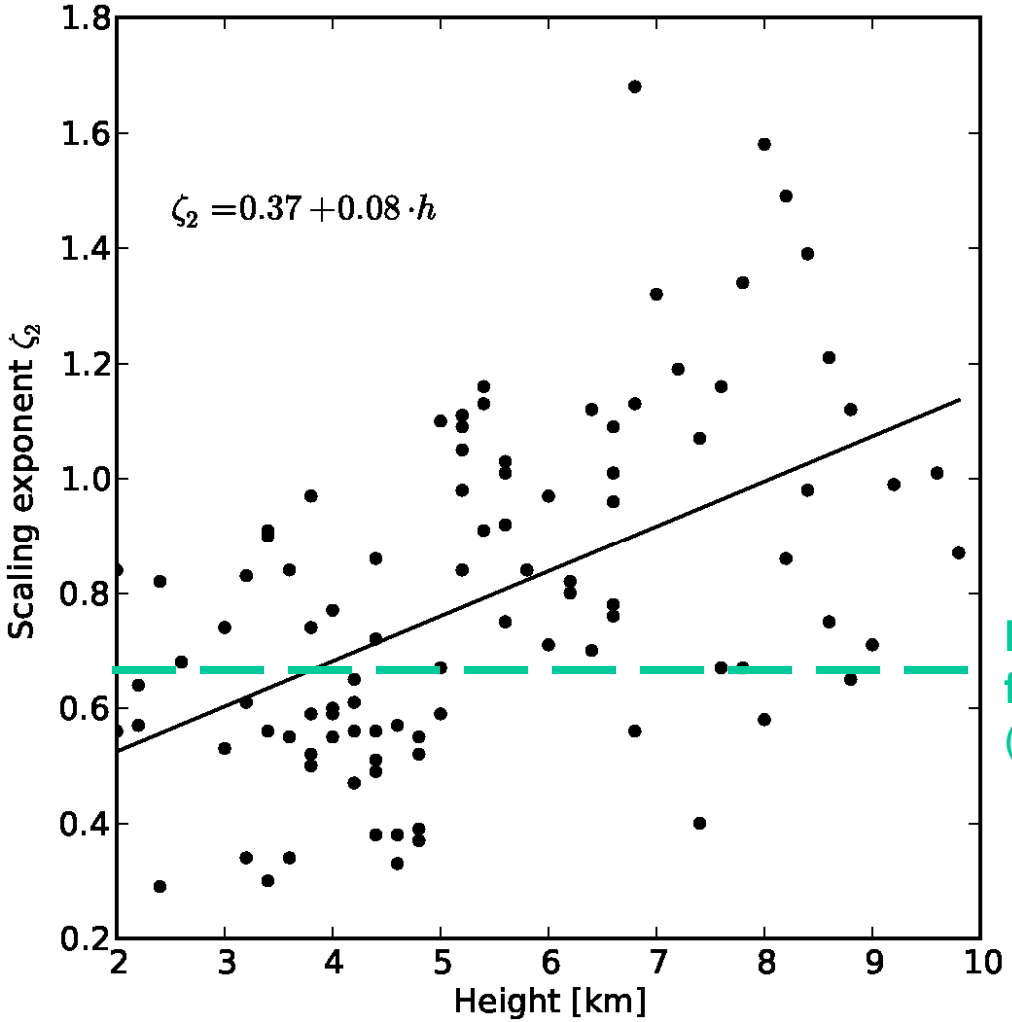
Comparison of Both Exemplary COPS Cases

Water vapour Lidar cross sections		
ALTITUDE	6.3 km – 9.7 km	2.0 km – 4.4 km
1st-order SF EXPONENT ξ_1	0.51 – 0.87 smooth time series	0.18 – 0.51 very rough time series
2nd-order SF EXPONENT ξ_2	0.87 – 1.58 very steep → little small scale influence	0.34 – 0.82 flat → lots of small scale fluctuations flatten the spectra
INTERMITTENCY	Small: mean ξ_∞ = 8.55	Large: mean ξ_∞ = 2.77
SITUATION	Atmospheric dynamics in the middle and upper troposphere dominated by large-scale processes	Atmospheric dynamics in the lower and middle troposphere controlled by convective moistening

smoothness ~ ξ_1 intermittency ~ $1/\xi_\infty$

enables quantifying and separating different situations

Scaling Exponent ξ_2 for all COPS Lidar Humidity Data



Total of 98 timeseries from 8 flights

Increase with height: physical meaning = loss of small-scale turbulent fluctuations

Passive scalar turbulent fluctuations: $\xi_2 = 2/3$
(Obukhov-Kolmogorov, 1941)

Result:
Statistics can be related to physics.

Conclusions

- First application of structure functions to airborne water vapour lidar data, to quantify intermittency and smoothness.
- Power-law scaling exponents behave like expected: intermittency parameter decreases with height, smoothness increases.
- Structure functions appear to be superior to the Fourier spectrum and show potential to distinguish underlying physical processes responsible for water vapour variability.
- Useful tool for verification of humidity distributions in climate & weather models.